X-ray Spectra of BL Lac Objects from the ROSAT Archive

G. Lamer[1], H. Brunner[1,2], and R. Staubert[1]

[1] Institut für Astronomie und Astrophysik, Abt. Astronomie, Universität Tübingen, Waldhäuserstr. 64, D-72076 Tübingen, Germany
[2] Astrophysikalisches Institut Potsdam, An der Sternwarte 16, D-14482 Potsdam, Germany

Abstract. We present ROSAT PSPC spectra of 74 BL Lacertae objects observed in the pointed observation phase. We have investigated the soft X-ray properties and broad band energy distributions and find a strong interdependence of X-ray spectral slope and radio to X-ray energy distribution. Objects with extreme values of $\alpha_{\rm rX}$ have flatter X-ray spectra than objects of intermediate $\alpha_{\rm rX}$. The properties of the objects can be modelled by a two component multifrequency spectrum with a hard (Compton) component and a steepening soft (synchrotron) component. We show that the differences between X-ray selected BL Lacs (XBLs) and radio selected objects (RBLs) are caused by a broad range of the synchrotron cutoff energies.

1. Observations and data analysis

Our sample comprises all BL Lac objects listed in the catalogue of Véron-Cetty & Véron (1993) and which are detected in a ROSAT PSPC observation with at least 50 source counts: 74 objects in total. The sample includes 19 objects of the *Einstein* EMSS sample (Morris et al. 1991) and 29 objects of the 5 GHz 1 Jy sample (Stickel et al. 1991). We reduced the data from the ROSAT archives at MPE and GSFC and fitted single powerlaw models with photoelectric absorption to the spectra. We calculated the broad band spectral indices $\alpha_{\rm rx}$, $\alpha_{\rm ro}$, and $\alpha_{\rm ox}$ from the ROSAT 1 keV fluxes, 5 GHz radio, and optical V band fluxes (Véron-Cetty & Véron 1993). The bin averages of spectral parameters and their statistical errors (Figs. 1+3) were determined from maximum likelihood confidence contours. All spectral indices α are given as energy indices ($f_\nu \propto \nu^{-\alpha}$).

We compared the fitted spectral indices with spectral simulations based on a set of simple two component models, including a hard power law component ($C_{\rm H}$) and a parabolically steepening soft component ($C_{\rm S}$) with different cutoff energies (Fig. 2) parameterized as follows:

$$C_{\rm S}(\nu) = 1 \qquad \text{for } \nu < \nu_1$$

$$\log_{10} C_{\rm S}(\nu) = \left(\frac{\log_{10}\nu_1 - \log_{10}\nu}{\log_{10} a}\right)^{\eta} \qquad \text{for } \nu > \nu_1$$

$$C_{\rm H}(\nu) = N \cdot \nu^{\alpha_{\rm H}}$$

The parameters used were $\nu_1 = 5 \cdot 10^{10}$, $\eta = 2.0$, $\alpha_{\rm H} = 0.7$, the normalization N was chosen so that $C_{\rm S}(5{\rm GHz})$ and $C_{\rm H}(1{\rm keV})$ are connected by a spectral slope $\alpha_{\rm rx,max} = 0.9$. A set of spectra with varying high energy cutoff was calculated using a grid of the parameter a ranging from $a = 100$ to $a = 6000$.

Simulated PSPC spectra were produced by applying a photoelectric absorption model (Morrison & McCammon 1983) with $N_{\rm H} = 3 \cdot 10^{20} {\rm cm}^{-2}$ and then folding the models with the detector response and fitting the resulting count rate spectra to absorbed single power law models.

2. Results

We find a strong dependence of the X-ray spectral indices on the radio to X-ray energy distributions of the objects. Particularly X-ray bright objects (with small values of $\alpha_{\rm rx}$) and radio bright objects (large $\alpha_{\rm rx}$) have flat X-ray spectra. Objects with intermediate values of $\alpha_{\rm rx}$ do have steep X-ray spectra (Fig. 1).

Figures 1+4 show that the X-ray spectra as well as the broad band properties are well reproduced by the two component spectral model. The variations in the broad band and X-ray spectra can be accounted for by varying the model parameter a, which adjusts the high energy cutoff of the soft component (see Fig. 2).

We find an average excess of fitted $N_{\rm H}$ compared to the galactic values (Stark et al. 1992, Elvis et al. 1989) (Fig. 3). According to our simulations the excess in fitted $N_{\rm H}$ caused by convex source spectra is small. Thus the excess is probably due to intrinsic absorption in some of the objects.

A detailed description of the results is given in Lamer et al. (1996), a preprint and a table file with the spectral data of all objects is available via WWW (http://astro.uni-tuebingen.de/prepre/).

3. Discussion

We interprete the dependence of $\alpha_{\rm x}$ on $\alpha_{\rm rx}$as a signature of a convex soft (synchrotron) and a hard (Compton) spectral component intersecting each other at different energies below, within, or beyond the soft X-ray band. The flat X-ray spectra of extremely radio bright BL Lacs is then due to Compton emission. The likewise flat X-ray spectrum of extremely X-ray bright objects can be explained by a synchrotron spectrum with a high energy cutoff beyond the ROSAT energy band. For the intermediate objects the synchrotron cutoff falls into the soft X-ray band giving rise to very steep PSPC spectra.

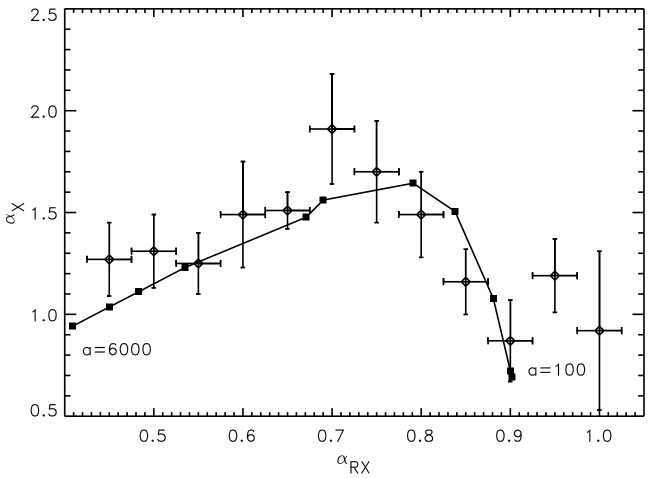

Fig. 1. Binned X-ray spectral slopes α_x vs. α_{rx} (data points) compared to spectral simulations (solid line).

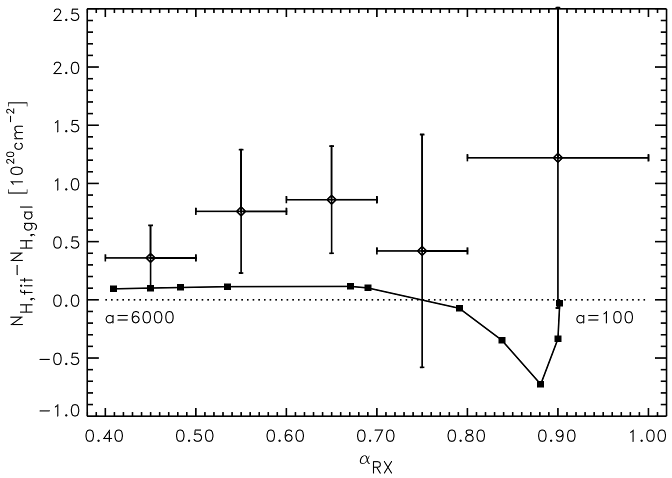

Fig. 3. Deviations of measured from galactic N_H averaged in bins of α_{rx} (data points) and deviations of fitted from true N_H due to spectral curvature as predicted by the spectral simulations (solid line).

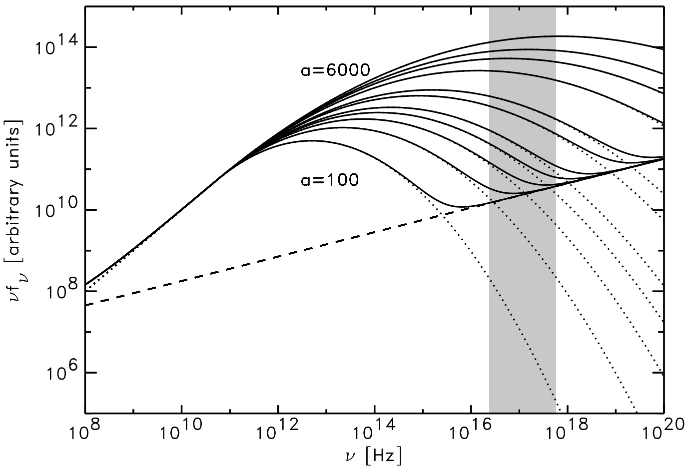

Fig. 2. Model spectra used for the simulations. Dotted: soft component C_S, dashed: hard component C_H, solid: $C_S + C_H$, shaded: PSPC energy range.

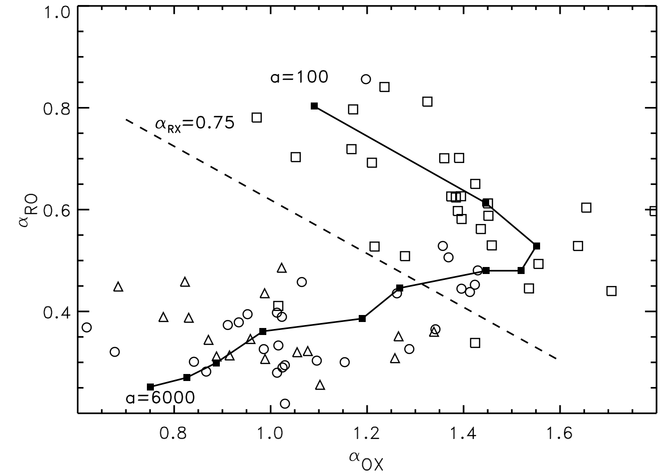

Fig. 4. Locations of object and simulated broad band spectra in the α_{ox} – α_{ro} plane. Triangles: EMSS sample, rectangles: 1 Jy sample, circles: others, solid line: spectral simulations.

As the new data require a broad range of synchrotron cutoff energies, it is unlikely that the differences of RBLs and XBLs are caused by different viewing angles (e.g. Ghisellini & Maraschi 1989, Celotti et al. 1993); probably the spectra of RBLs and XBLs are intrinsically different as suggested by Padovani & Giommi (1995).

Acknowledgements. This work was supported by DARA under grant 50 OR 90099. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by JPL, Caltech, under contract with NASA.

References

Celotti, A., Maraschi, L., Ghisellini, G., Caccianiga, A., and Maccacaro, T., 1993, ApJ, 416, 118
Morris, S.L., Stocke, J.T, Gioia, I.M., et al. 1991, ApJ, 380, 49
Morrison, R., and McCammon, D. 1983, ApJ, 270, 119
Elvis, M., Lockman, F.J., and Wilkes, B.J., 1989, AJ, 97, 777
Ghisellini, G. and Maraschi, L., 1989, ApJ, 340, 181
Lamer, G., Brunner, H., Staubert, R., 1996, A&A, in press
Padovani, P., and Giommi, P., 1995, ApJ, 444, 567
Stark, A.A., Gammie, C.F., Wilson, R.W., et al., 1992, ApJS, 79, 77
Stickel, M., Padovani, P., Urry, C.M., Fried, J.W., and Kühr, H. 1991, ApJ, 374, 431
Véron-Cetty, M.P., and Véron, P., 1993, ESO Scientific Report, 13